44 Manufacturing Execution Systems

ZAMEER PATEL

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INTRODUCTION

In this global age, all types of process, manufacturing, and production industries face challenges to make continuous improvements on their products. Products need to be of good quality with minimum defects, lower cost, little waste, quick turnaround, and in large volumes. All these demands require industries to be adaptable, agile, and flexible in their production practices.

Manufacturers, for example, can track and optimize their supply chains, but they still need to get an accurate picture of what is being produced, how it is produced and who is producing it on the shop floor. In this respect, manufacturing execution systems (MESs) have emerged as a powerful tool for integrating the information gathered from the plant floor with the management. Consequently, MES closes the gap between the front office and the shop floor in plants.

The MES is an information and communication mechanism that takes care of the translation between process information on the shop floor to assist the managerial, financial, and logistical strategies at the office. Its objective is to control and improve all aspects that influence the production processes to achieve good flexibility and lower production costs, thus leading to higher profits.

An MES is an integrated hardware and software solution that measures and controls activities in the production areas of manufacturing organizations. MES software focuses on plant activities and provides the real-time information needed to react to events timely as they occur. It collects data directly from plant floor equipment and operators and provides real-time feedback to operators, supervisors, and managers. The primary functionality of MES includes production monitoring at the plant floor, reporting, genealogy, planning, and scheduling, which will be explained in this chapter.

DEFINITIONS

MESs also referred to as manufacturing operations managements (MOMs) are a set of activities that coordinate the personnel, equipment, material, and energy in the conversion of raw materials into products. MES and MOM include activities that may be performed by physical equipment, human effort, and the information systems.

The Manufacturing Enterprise Solutions Association (MESA) International (http://www.mesa.org/index.php?page=overview) describes as follows: “MES delivers information that enables the optimization of production activities from order launch to finished goods. Using current and accurate data, MES guides, initiates, responds to, and reports on plant activities as they occur. The resulting rapid response to changing conditions, coupled with a focus on reducing non value-added activities, drives effective plant operations and processes.”

The raw data gathered on the plant floor does not carry any significance on its own. However, the raw data converted to meaningful business decisions by structuring and establishing relations between various items and presenting these relations in a clear form can be used as an effective decision support tool. As it can be seen in Figure 44.1, the “decision efficiency” can increase significantly if this information is used in combination with other functional knowledge and experience. It is important to understand that it may be impossible to entirely automate the production processes and logistical operations in an organization since they can frequently change. Even if fully automated, the people in charge of the operations and the management will have to make many decisions on what to do next and how to do it. The quality of these decisions determines the overall performance of the company.

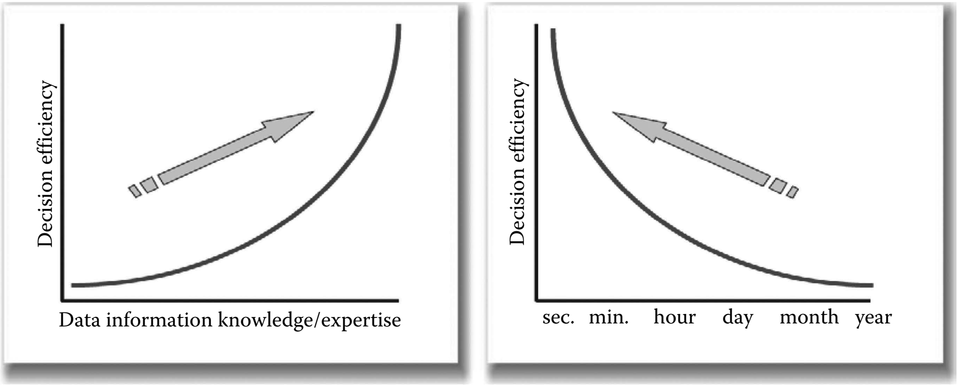


FIG. 44.1
Decision efficiency diagram. (From MES Product Survey 2008 and 2009. Available from Logica MES Center of Excellence at www.logica.com (accessed May 3, 2010).) Note: Product Survey can be ordered at http://www.mescc.coma0r or http://www.logica.com/

The value of information also depends upon its timely availability. In production lines, the timely availability of information becomes essential to react effectively to alarms, events, trends, and many other problems. Thus, the speed of communication and timely information play an important role in the decision efficiency. However, the time lines, which help decision efficiency, could vary at different levels in an organization starting from the production process where day-to-day operations take place to the enterprise level at which business decisions are taken based on the short- and long-term plans and targets set by the management.

In this respect, the MESs provide real-time information of the plant operations to buyers, procurement, customers' services, sales representatives, distribution, and logistics managers in addition to the traditional users inside the plant. For example, the inventory and work in progress can correspond to significant costs in a supply chain exerting constant pressure for a lean supply chain with minimum inventory. The plant or shop floor visibility offers this vital real-time link to the entire supply chain, thus providing better control over the operations and visibility on the processes. Particularly, for industries having multiple plants, MES provides the flexibility to view the production tasks executed at each plant. This provides coordination to meet the market requirements.

MESA AND MES FUNCTIONS

The MESA, international organization founded in 1992, is an association made up of manufacturers, solution providers, and industry professionals for the purpose of promoting best practices. It defines industry standard methodologies and approaches for deployment of plant information solutions. MESA developed 11 functions of MES often drawn in the form of "Honey-Comb" as shown in Figure 44.2. The 11 MES functions clearly identify the related issues as well as help us gain understanding on the various subcomponents of an MES and their functionalities.

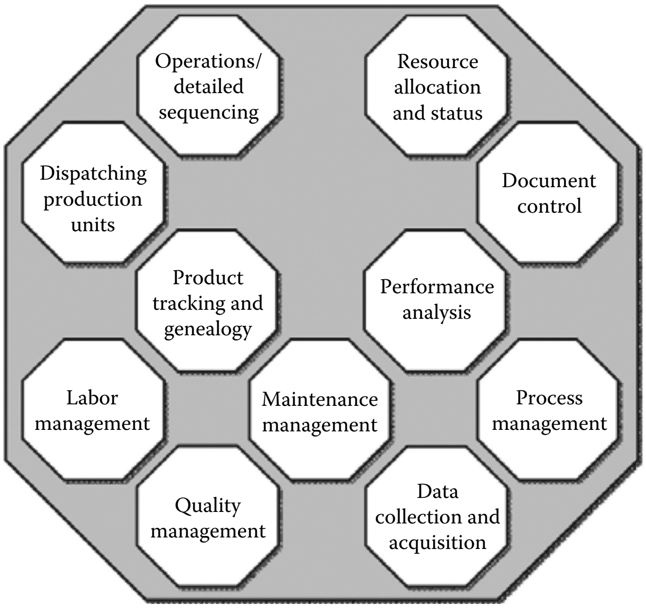

Operations/ detailed sequencing
Resource allocation and status
Dispatching production units
Document control
Product tracking and genealogy
Performance analysis
Labor management
Maintenance management
Process management
Quality management
Data collection and acquisition

FIG. 44.2
Eleven MES functions—MESA Honeycomb. (From MESA Lean Manufacturing Initiative Guidebook, 2008. Can be viewed at: ftp://public.dhe.ibm.com/software/plm/pdif/MESA_SOAinManufacturingGuidebook.pdf (accessed May 12, 2010).)

The brief explanations of 11 MES functions are as follows:

Resource allocation and status: The resources include machines, tools, labor skills, materials, equipment, and other entities such as documents necessary for a particular operation. It provides detailed history of resources and insures that equipment is available and can properly be set up on the real-time basis. The management of these resources includes reservation and dispatching of resources to meet scheduling objectives.

Document control: This function controls records that must be maintained with the production unit. Documents, including work instructions, recipes, drawings, standard operation procedures, part programs, batch records, engineering change notices, and shift-to-shift communication. It has the ability to edit "as planned" and "as built" information. It sends instructions to the operators providing data or recipes for device controls. It can also include the control and integrity of environmental, health and safety regulations, and ISO information such as corrective action procedures, storage of historical data, and so on.

Performance analysis: It provides up-to-the-minute reporting of operation results along with the comparison of the past history and the expected future business results. Performance results include measurements as resource utilization, resource availability, product unit cycle time, conformance to schedule, and performance to standards of statistical quality control (SQC) and statistical process control (SPC). It is based on the information gathered from different functions that measure operating parameters. These results are prepared as a report or presented online as the current evaluation of performance.

Process management: It monitors production for automatic corrections or for providing decision support to operators to improve in-process activities. These activities may be intra-operational focusing specifically on machines and equipment as well as inter-operational for tracking the process from one operation to the next. It may include alarm management systems to make sure that the personnel are aware of process changes that may be beyond the acceptable tolerances. It also provides interfaces between intelligent equipment and MES through the data collection and acquisition mechanisms.

Data collection and acquisition: This function provides an interface link for operational data related to a production unit. The data may be collected either manually or automatically from set of equipment on up-to-the-minute time frame.

Maintenance management: Tracks and directs the activities to maintain equipment and tools for their availability when needed. It ensures scheduling for periodic or preventive maintenance as well as providing a timely response to immediate problems. It maintains a history of past events or problems to aid in diagnosis of possible problems.

Quality management: It provides a real-time analysis of plant floor measurements to assure product quality control and to identify problems that may require attention. It identifies causes of the problems and recommends actions for correcting the problems, correlating the symptom, and actions to be followed for corrections. It includes SQC and SPC tracking and management for off-line inspections, and the analysis in the laboratory together with the laboratory information management system.

Labor management: It provides status of personnel including time and attendance reporting, certification tracking, and indirect activities such as the material preparation or tool room work for activity-based costing. It interacts with resource allocations to determine optimal assignments.

Product tracking and genealogy: It provides the visibility and the status of the work and its disposition. The information may include who is working on it, components and materials by the suppliers, serial numbers, current production conditions, alarms, necessary reworks, and other exceptions related to the products. The on-line tracking function creates a historical record allowing traceability of components and their usage of each end-product.

Dispatching production units: It is designed for managing the flow of production units in the form of jobs, orders, batches, lots, and work orders. The dispatch information is presented in sequence in which the work needs to be done and the changes necessary as the events occur on the factory floor and to alter prescribed schedules in real time. Rework and salvage processes are also available as well as the ability to control the amount of work in progress at any point in time.

Operations/detail scheduling: It provides sequencing based on priorities, attributes, characteristics, and/or recipes associated with specific production units in operation. It recognizes alternative and overlapping and parallel operations in order to calculate exact time or equipment loading in detail and adjust to shift patterns.

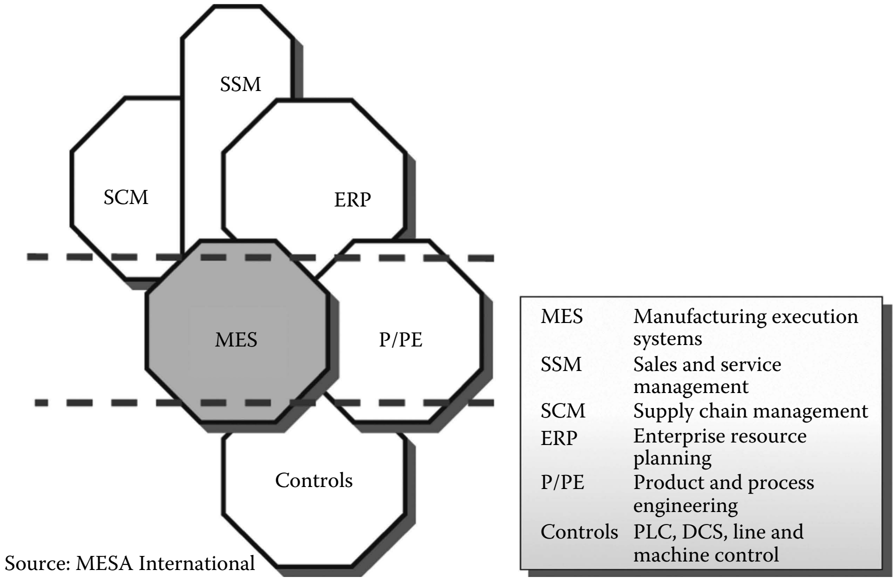
INTEGRATION OF MES IN ORGANIZATIONAL ACTIVITIES

Many organizations typically will have various information systems in operation in addition to MES. Information needs to be exchanged between these systems. Figure 44.3 shows that there may be no clear boundaries between the systems and they may have considerable overlap. Since the overlap of the MES with others is more likely, it becomes one of the main integrating tools in the plant. The borders are drawn based on a specific situation of the end user who can choose which products or systems can be used best and where exactly the distinctions need to be made.

When implementing MES, the question that often arises is the functional boundaries or divisions between MES and other systems especially between MES and enterprise resource planning (ERP). However, various levels are defined by ISA-95 showing the functional hierarchy to make a clear distinction between these different layers and hence to help draw boundaries between these systems.

Functional Hierarchy ISA-95

ISA-95 part 3 defines five levels of functions and activities of a manufacturing organization, as illustrated in Figure 44.4. This functional hierarchy defines the levels at which decisions are made within a firm. The levels 0, 1, and 2 correspond to the line supervisory functions, operations function, and process control functions, respectively. It is important to understand the MES or MOM forms the level 3 in the context


SSM
SCM
ERP
MES
P/PE
Controls
MES Manufacturing execution systems
SSM Sales and service management
SCM Supply chain management
ERP Enterprise resource planning
P/PE Product and process engineering
Controls PLC, DCS, line and machine control

Source: MESA International

FIG. 44.3
Context information systems. (From MESA Lean Manufacturing Initiative Guidebook, 2008. Can be viewed at: ftp://public.dhe.ibm.com/software/plm/pdif/MESA_SOAinManufacturingGuidebook.pdf (accessed May 12, 2010).)

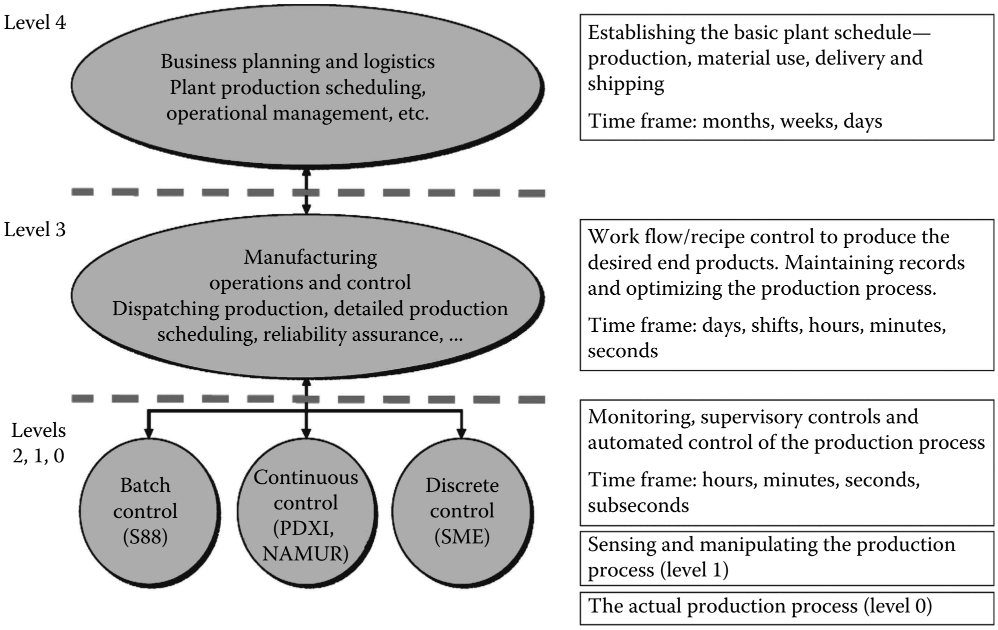

Level 4
Business planning and logistics
Plant production scheduling,
operational management, etc.
Establishing the basic plant schedule—production, material use, delivery and shipping
Time frame: months, weeks, days
Level 3
Manufacturing
operations and control
Dispatching production, detailed production
scheduling, reliability assurance, ...
Work flow/recipe control to produce the desired end products. Maintaining records and optimizing the production process.
Time frame: days, shifts, hours, minutes, seconds
Levels 2, 1, 0
Batch control (S88)
Continuous control (PDXI, NAMUR)
Discrete control (SME)
Monitoring, supervisory controls and automated control of the production process
Time frame: hours, minutes, seconds, subseconds
Sensing and manipulating the production process (level 1)
The actual production process (level 0)

FIG. 44.4
Functional hierarchy (ANSI/ISA-965 Part-1).

of this hierarchy with ERP and business systems forming the fourth level. Levels are:

1. *Level 0* defines the physical processes.
2. *Level 1* defines the activities involved in sensing and manipulating the physical processes. Elements of Level 1 are the sensors and actuators in automation systems.
3. *Level 2* defines the activities of monitoring and controlling the physical processes. In automated systems, this includes equipment control and equipment monitoring. At this level, automation and control systems have real-time responses measured in sub-seconds and typically are implemented in various forms such as programmable logic controllers, distributed control systems (DCSs), and open control systems.

4. *Level 3* defines the activities that coordinate production resources to produce the desired end products. It includes workflow control and procedural control through recipe execution. Level 3 typically operates on time frames of days, shifts, hours, minutes, and seconds. Level 3 functions also include maintenance, quality assurance and laboratory, and inventory movement.
5. *Level 4* defines business-related activities used to manage an organization. Production-related activities include establishing the basic plant schedule (such as material use, delivery, and shipping), determining inventory levels, logistics control, and material inventory control so that materials are delivered on time to the right place. Level 4 is called business planning and logistics and it operates on time frames of months, weeks, and days. The ERP logistics systems are used to automate Level 4 functions.

It is important to remember that each level provides some form of control, and has its own definition of real-time. Level 3 systems consider real-time to mean information available a few seconds after the shop floor events occur. Level 4 systems consider real-time to mean logistics and material information is available daily or within a few hours after the end of a shift.

SOFTWARE SUPPORT

MES software is designed to collect production-related information from automated production equipment, sensors, personnel, and other software systems. It can monitor and control quality parameters, facilitate communication inside the production facility among personnel and machines and facilitate communication beyond the facility to suppliers, provide information to personnel and machines necessary to perform production activities, customers, engineers, sales, and management.

There is a wealth of commercially available MES software. Many of these software concentrate on the core functionality with MES to ensure availability of resources such as raw material supplies, and efficiently when demanded. Based on resources, MES creates a work plan and releases the necessary orders. The work in progress can then be tracked along its various stages using the monitoring and other tools available with MES such as operator display, schematics, and generates reports. Once the instructions are executed MES then updates the ERP system with the production quantities and the other details associated with the work orders. For example, Tuppas manufacturing software modules (http://www.tuppas.com/MES-Software/MES-Software.htm) provide the following functionality:

- Production, scrap, and downtime reporting
- Production scheduling
- Job tracking
- Defect tracking
- Statistical control
- Process control
- Quality management
- Inventory management
- Supply chain management
- Barcoding applications
- Job costing

Dataflow and Usage

The typical MES data flow for a real-time enterprise is shown in Figure 44.5. From the data flow diagram, it can be seen that the customer orders are first received at the enterprise level by an ERP or SAP system. This customer order is then converted into a work order and passed on to the next stage, which is MES. The work instructions based on the nature of the order are then passed onto the DCS or the control level, which controls and executes the work order into production using the various resources such as the workforce and the equipment.

Leveraging MES

The MES could be applied where one can actually put in place a mechanism to ensure corrective action is taken immediately once an out of spec condition is recognized. Figure 44.6 is an example of how predefined business rules can be implemented. These rules govern the use of MES under predetermined circumstances. For example, when a machine goes down, we want to immediately notify the relevant personnel who can rectify the situation (maintenance department, production supervisor, possibly plant management). Then we want to take steps to rectify the situation and notify any other impacted systems of this occurrence. We want this to happen automatically and not wait for people to recognize this problem and then determine what needs to be done.

Another example of a business rule can be when an item of below specification is detected on a batch of product, the operations personnel is automatically alerted to this event and production reports automatically are generated to determine the cause. Modeling environments can also automatically adjust production parameters; ensuring higher yields for future batches. The objective is to close the loop on the process as rapidly as possible, and this type of modeling helps in taking immediate action. Clearly, no additional production is jeopardized due to a lag in the data gathering, analysis, and reporting process. The systems can be setup such that alerts and notifications are sent via e-mail or SMS thus being proactive in terms of the overall approach to enhance stability of plant operations and hence lower the downtime.

IMPORTANCE AND BENEFITS OF MES

Globalization has meant many products are produced and sold across the globe. It has become extremely difficult to

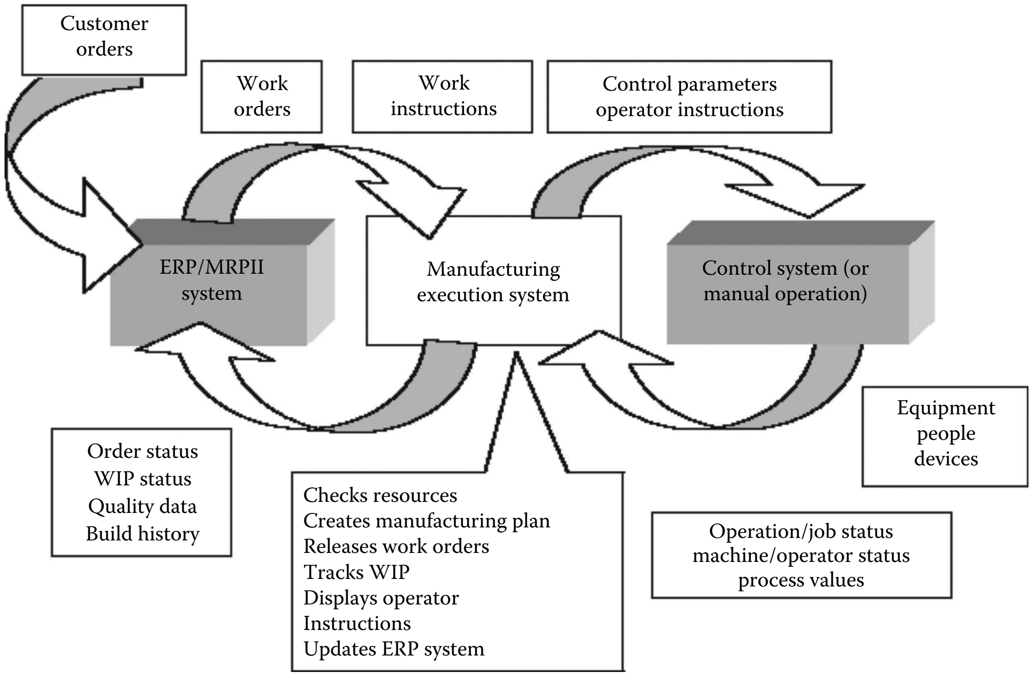


FIG. 44.5
MES in an enterprise data flow.

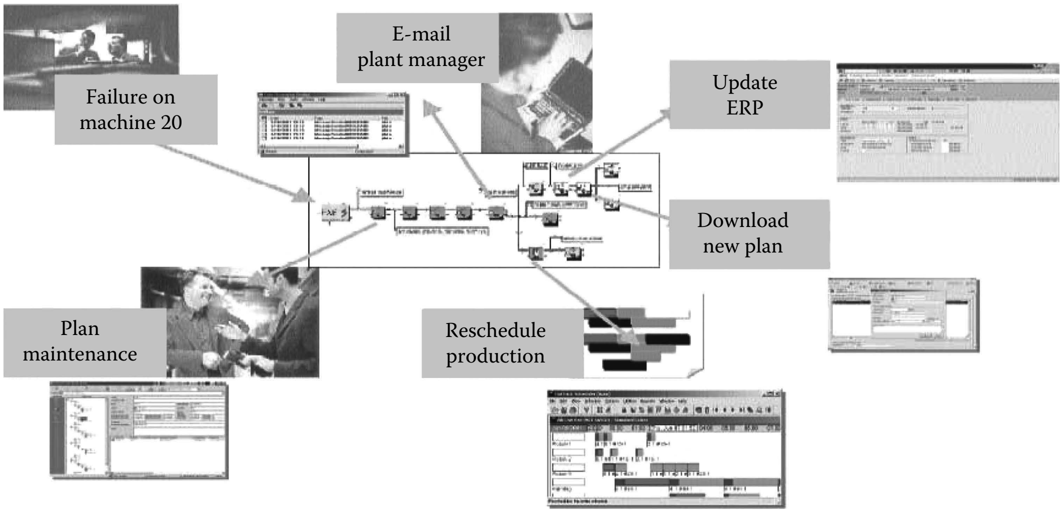
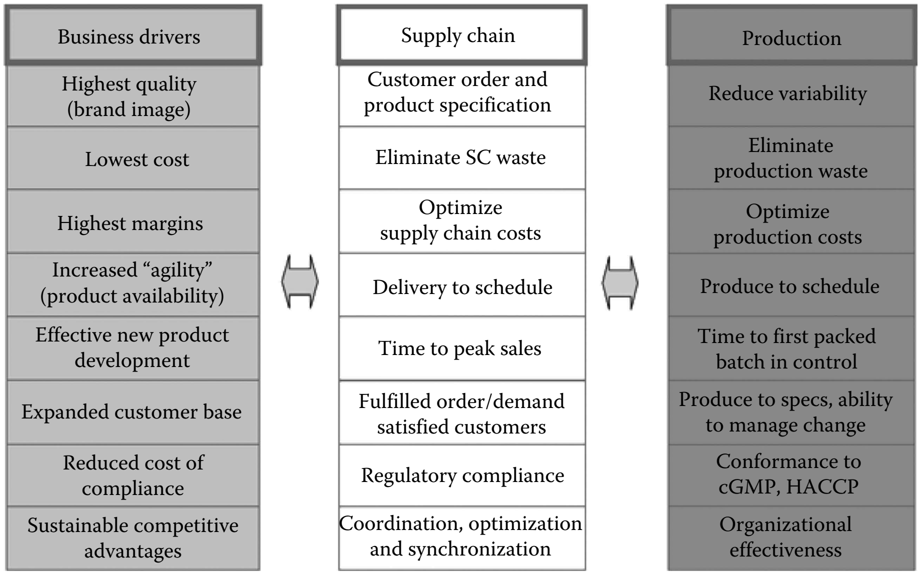


FIG. 44.6
Production rule handling machine failures.

accurately predict variations in the overall demand for a particular product. This has led to “demand-driven” models necessitating the tracking of every piece of data that can help to maintain an accurate inventory to meet the demand timely. This problem is partially solved by keeping the inventory levels down on the supplier side and getting accurate demand data at the customer side. However, the missing piece of the puzzle has been the link in the supply chain pertaining to the data generated at the shop floor, which was typically not captured and integrated into the system thus could not have a clear visibility into the operations across the globe. In an era, where customers expect instant fulfillment of orders at extremely competitive prices and the highest quality, there is no option but to bridge this information gap.

In Figure 44.7, business drivers are mapped with the supply chain elements and production environment elements. In order to successfully counter and meet the challenges of the market and the supply chain, the production cannot be a black-box anymore. In this context, the plant floor performance becomes the key point.



Business drivers		Supply chain		Production
Highest quality (brand image)		Customer order and product specification		Reduce variability
Lowest cost		Eliminate SC waste		Eliminate production waste
Highest margins		Optimize supply chain costs		Optimize production costs
Increased "agility" (product availability)	⇔	Delivery to schedule	⇔	Produce to schedule
Effective new product development		Time to peak sales		Time to first packed batch in control
Expanded customer base		Fulfilled order/demand satisfied customers		Produce to specs, ability to manage change
Reduced cost of compliance		Regulatory compliance		Conformance to cGMP, HACCP
Sustainable competitive advantages		Coordination, optimization and synchronization		Organizational effectiveness

FIG. 44.7

Relationship between business drivers, supply chain, and production.

The need for visibility in a global supply chain is critical producers deal with different cultures, different markets, and different styles of doing business. For example, operating at a global level also means that organizations have to work with different suppliers. This brings up the challenge of maintaining the same level of quality across all manufacturing locations for a particular product. Additionally, global producers, as in the case of food and beverages industry, need a capability to alter product formulas and factor in alternatives in case a particular product or its component is banned in a particular country. Various governments have also enforced laws for being able to trace the genealogy of their products. For example, product genealogy is extremely important in tracing the source of epidemics such as the mad cow disease. In such cases, producers need to have a capability to recall defective products or its components. In this respect, MES has become a vital need.

With state-of-the-art MES or MOM systems combine technologies such as the Internet, web services, radio-frequency identification, and other real-time shop floor technologies. Manufacturers can now gain visibility into their entire supply chain, from source through consumption. MESs in effect add the following values to an organization:

1. *Eliminate non-value-added steps:* Technology can be used to automate certain steps on the plant floor, like data collection, in order to keep personnel focused on direct value-added activities. Integrating systems across the engineering, operations, and quality departments can streamline processes, eliminating manual steps and time wasted in activities.
2. *Provide real-time performance visibility:* Real-time performance visibility is required to support effective program metrics and decision making. An improvement program such as *Lean* is highly dependent upon the accuracy and timeliness of the data produced and collected during the production processes, including machine uptime, process cycle time, or days of work in place inventory. These data are critical for continuously improving the process. Technology provides a visual window into plant floor status and issues, as well as a method for making real-time decisions to optimize flow and resolve constraints.
3. *Enhance visual controls:* The goal of visual controls is to make the job more intuitive. Well-designed manufacturing systems can enhance the display of important information to plant floor personnel. Information like out-of-control alerts can be displayed in real-time basis when necessary. Online standard procedures and graphical work instructions are used as visual controls for the shop floor.
4. *Standardize work processes:* Standard disciplines and work practices, including production sequences and methods, work instructions, and quality and safety checks can conveniently be implemented and controlled. These standard processes provide consistency and reliability while minimizing the errors.
5. *Track one-piece flow efficiently:* With the availability of information systems, following one unit through the plant floor is just as easy as following many units and, when considering activities like splitting work orders to work around production issues, following one unit may be much easier. Information technology systems alleviate the need for combining multiple units into a single work order to reduce the overhead of paperwork and scheduling.
6. *Identify and resolve constraints:* Production systems can be configured to raise alerts based on rules and

immediately flag issues in real-time. Specialized scheduling software is also useful in high-mix environments, where constraints are always changing depending on the jobs in the current process.

7. *Enable quick product line changes:* Changing business needs and processes require flexible software, as processes designed and deployed today inevitably will require changes in the future. Business process changes can significantly affect those doing the work, as well as the materials, equipment, and services provided. Relying on manual processes and tools to provide the flexibility necessary to meet these demands can introduce error and waste, both in time and materials. Processes designed to embrace business changes can provide a robust platform upon which to base both today's initiative and future improvements.
8. *Track process improvements:* Information systems also are required to track ongoing process improvement initiatives and progresses. These systems provide a shared knowledge base with visibility of prior achievements, which is essential in creating a culture that promotes continuous improvement.
9. *Improve product quality by reducing variability:* Quality management is so important to achieving lean. A major reason for this is that quality issues historically have been identified as a major source of time and material waste. Examples of how systems help quality improvement efforts include:
   a. Automation of inspection and data collection
   b. Real-time alerts for out-of-control situations based on statistical analysis
   c. Systematic enforcement of sampling and auditing rules
   d. Tracking of corrective action efforts

COLLABORATIVE MES

MESA in the year 2004 published the collaborative Manufacturing model also referred to as "c-MES" with eight core MES functions as illustrated in Figure 44.8, in realization that manufacturers are increasingly required to compete as supply chains instead of as individual elements.

In c-MES, the production is a key element for delivering high service levels to customers. In the context of a supply chain, each plant is only one element in the overall chain. In order to maintain competitive edge, the manufacturers are required to collaborate with many others such as the customers, distributors, material and product suppliers, contractors, etc. Hence, an effective coordination and synchronization of many diverse activities become a necessity. MESA international defines collaborative manufacturing as "A strategy by

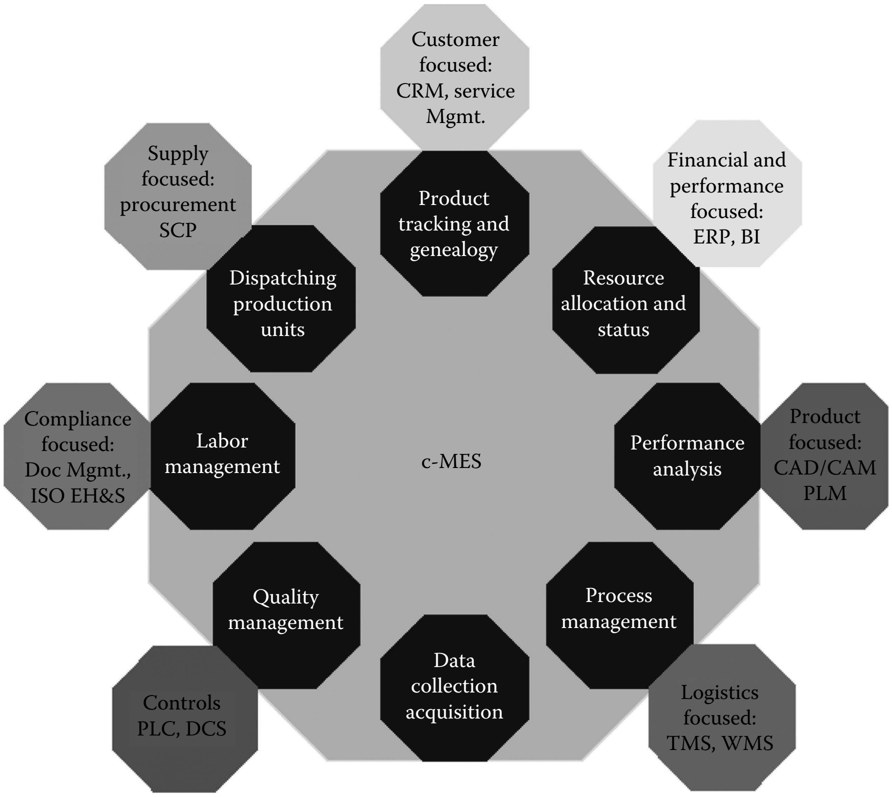

Customer focused: CRM, service Mgmt.
Supply focused: procurement SCP
Financial and performance focused: ERP, BI
Product tracking and genealogy
Dispatching production units
Resource allocation and status
Compliance focused: Doc Mgmt., ISO EH&S
Labor management
c-MES
Performance analysis
Product focused: CAD/CAM PLM
Quality management
Process management
Data collection acquisition
Controls PLC, DCS
Logistics focused: TMS, WMS

FIG. 44.8
Collaborative c-MES. (From MESA Lean Manufacturing Initiative Guidebook, 2008. Can be viewed at: ftp://public.dhe.ibm.com/software/plm/pdif/MESA_SOAinManufacturingGuidebook.pdf (accessed May 12, 2010).)

which all appropriate individuals and organizations—both internal and external to the legal enterprise work together." The primary objective behind these strategies is to improve the supply chain processes, provide timely and meaningful information for better and effective decisions.

SUMMARY OF KEY FEATURES OF MES

Summarized key features of an MES include the following:

- Automate management of recipes
- Production report
- Product/goods/materials tracking
- Scheduling and sequencing
- Key performance indicator (KPI) tracking
- Event (and exception) management
- Intelligent decisions that can influence production and cost management
- Manage and measure of operational equipment efficiency
- Improve and ease the management of resources, which includes inventory and personnel

A fully integrated system will show real returns; from the ability to monitor KPI in real-time on productivity, quality, and yields. Managing inventory locations and raw materials; isolating or reprocess nonconforming products through remediation processes can also be carried out. Thus, integration of MES/ERP becomes key enabler for a more profitable, responsive business.

Conclusions and Comments

Due to growing interest shown in service-oriented architecture, MES vendors too have started reengineering their products around Microsoft's.Net technology or J2EE. This allows MES to invoke web services. For example, MES majors such as Rockwell Automation have tried to close the gap between plant control systems and business planning. As the challenges for the manufacturing industry continue to escalate, a need for global visibility has become imperative. Not surprisingly, MES are increasingly being viewed to be filling the vital missing link between the plant floor information with business management information mainly provided by applications such as ERP and CRM. In an era marked by regulations and intense competition, for many organizations, MES is becoming an absolute necessity for staying competitive.

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